Kinetic Energy Storage:
Solving Problems For Power Engineers Around The World

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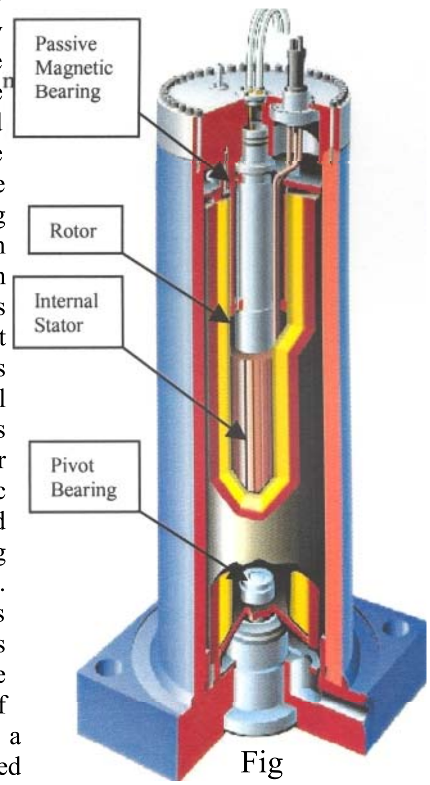
Introduction

The objective of this paper is to raise awareness of how the use of short-term energy storage can contribute to the resolution of some problems encountered by power engineers. Before going in to a number of case studies, a brief description of the core technology is included.

The UPT Kinetic Energy Storage System (KESS)

With over twenty installations around the world, high-speed composite Flywheel technology is becoming an accepted technique for the resolution of Power and Energy management problems. At the heart of the UPT Kinetic Energy Storage System (KESS) is a 900mm long by 330 mm Outside diameter tubular rotor made up of carbon and glass fibre composite that weighs 110kg. The bore of the rotor is lined with a patented magnetic loaded composite that is impulse magnetised to produce the poles of the motor generator and the passive magnetic bearing. The top speed is 630 Hz with a surface speed equal to 1400mph resulting in the need to operate in a "medium " vacuum level to prevent friction heating. Each unit stores 16MJs of energy of which up to 12MJs can be usefully used depending on the application. The control electronics consist of a conventional 3-phase IGBT voltage source inverter that interfaces the ac motor generator with a dc bus. Power control is achieved by a patented synchronous pulse width and phase control system that allows the system to provide maximum power in less than 5ms. The design life of the rotor and bearings is twenty years or 10 million discharges. Units can be ganged together on a common dc bus without any interconnection allowing powers levels to be tailored to suit the application. Units can be added or subtracted during operation allowing maintenance to be carried without loss of service. In critical applications an n+l approach is used with all units being supported by their own services. The flywheel and bearings are maintenance free, the only maintenance being checks of the vacuum pump oil and cooling systems on an annual basis. In terms of power the basic traction unit, the tr200, can deliver 200kW over a voltage range of 580 to 900volts dc. Up to 250 kW can be delivered for 25seconds when the dc bus is 700volts.



Fig

Control Algorithm

The control algorithm at the heart of the control program calculates the required energy flow (both in direction and magnitude) based on the DC bus voltage. The power profile, figure 2, illustrates how this is set up. It contains three distinct control regions; discharge, recovery and charge, typical voltage levels for a traction application with a no-load voltage of around 630 volts are illustrated. While the track DC voltage is below 620 volts, e.g.. during train motoring, the rate of energy transfer to the track (discharging) is in proportion to the voltage down to 600 and at the maximum rate below 600 volts. Conversely, during regenerative braking, while the track voltage is above 650 volts, energy transferred from the track to the cylinder (charging) is proportional to the voltage up to 690 volts, and at the maximum rate above 690 volts. The control profile enters the recovery region while the track voltage is between 620 and 650 volts. This region can be used to realign the cylinder speed to a mid-point energy equivalent or any other pre-defined level depending on the application, at a pre-defined power level. Actual values of DC voltage have been given in the preceding section in order to simplify the explanation. In reality, all voltages are derived as offsets from a nominal no-load voltage level.

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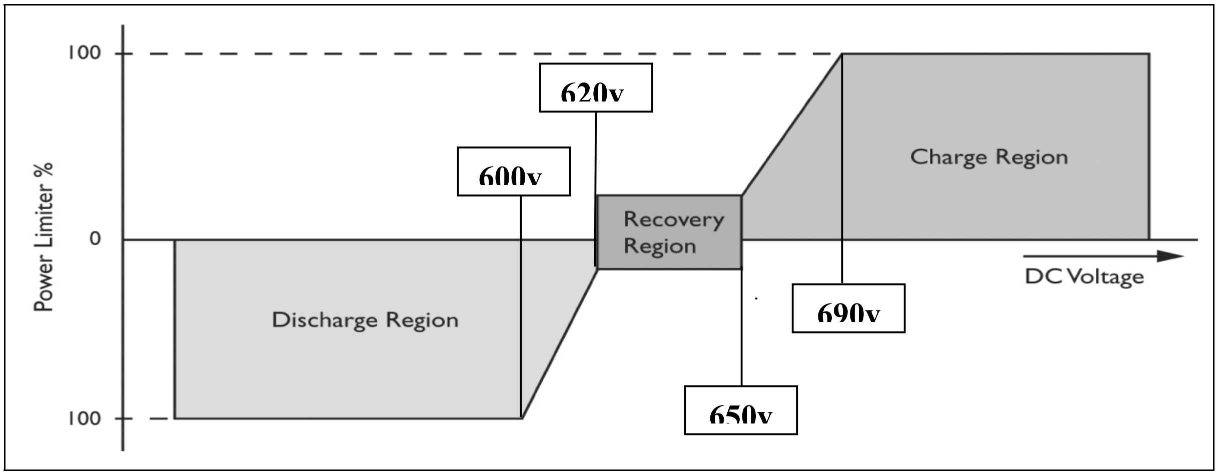


FIGURE 2 GRAPHICAL REPRESENTATION OF CONTROL ALGORITHM

SYSTEM RELIABILITY AND FLEXIBILITY

Each energy storage unit operates by direct connection to a DC bus. Units can be operated individually or in groups. Typical traction power demands require much larger power ratings than that from a single UPT KESS unit. For system flexibility and enhanced reliability, and to cater for possible future expansion, each UPT KESS operates as a single system, independent of other units. This modularity is achieved by ensuring that all power transfer decisions are made solely from the value of the DC bus voltage, which is common to all units. Further units can be added when required, and the load demand automatically shared between all units. The use of multiple unit installations leads to higher system availability and allows on line maintenance by enabling the withdrawal of one unit leaving the others to carry on automatically sharing the small additional load.

APPLICATIONS ENGINEERING

The system can be configured to give Voltage support, improving line receptivity, Power levelling and mid-point energy saving. These control algorithms also apply to systems other than traction including high-speed lifts, deep mine winches and quayside cranes as well as smoothing the output from wind turbines, etc..

In Voltage Support applications the control profile is configured to keep the flywheels at or near maximum energy during periods of infrequent train movements. The energy to recharge the KESS units is drawn at low power over longer periods between train movements. Line Receptivity Enhancement is used where the frequency of train movements is insufficient to maintain the lines ability to capture the re-generative braking energy. In this application the KESS system is configured to keep the flywheels towards the minimum speed between operations so as to provide a high power energy store to capture the energy during train deceleration. The energy captured can either supply a high power energy source during train acceleration or low power energy source between train movements. Power Leveling requires the KESS system to be configured to act as both a current source and sink at variable power levels in order even out the power demand and to limit the peak power demands on existing substations. Power leveling is best achieved by setting the control profile to give a near balanced power capability in both charge and discharge responses. This configuration is used in conjunction with Wind Turbines to smooth out the effects of gusting.

RESULTS FROM TRIALS AND APPLICATIONS: -

LONDON UNDERGROUND PROOF OF PRINCIPLE

The trials consisted of 3, 100kW machines mounted at the "North Fields" to "Acton" test track. The results confirmed our ability to model the effect of the KESS system, demonstrated the machines ability to share the load evenly without any inter-connection as well as showing a potential 28% saving of energy.

New York – USA

A 1 MW system has been installed at New York City Transit's test track at "Far Rockaway". The primary aim was to demonstrate the technologies ability to support track voltage with an additional benefit of energy conservation. The system consists of 10 off 100kW machines mounted in a custom built facility at the " Far Rockaway" train test track that runs parallel to the line connecting "Kennedy Airport" to the New York City

Transit system. It has now been operational for 10,000 hours reinforcing the voltage of the test track during testing of the new trains being supplied to New York City Transit as well as reinforcing the voltage in this area during normal operation.

Voltage Support

Figures 6 and 7 show the voltage levels with and without KESS support. The voltage, without KESS support, dropped typically from a high of 687v when a train is braking down to 625 when the train was accelerating. Voltage regulation at the Far Rockaway test track was poor, even with the no load voltage set at 680v the voltage drops below 600volts during train acceleration trials when a normal train passed the test track.

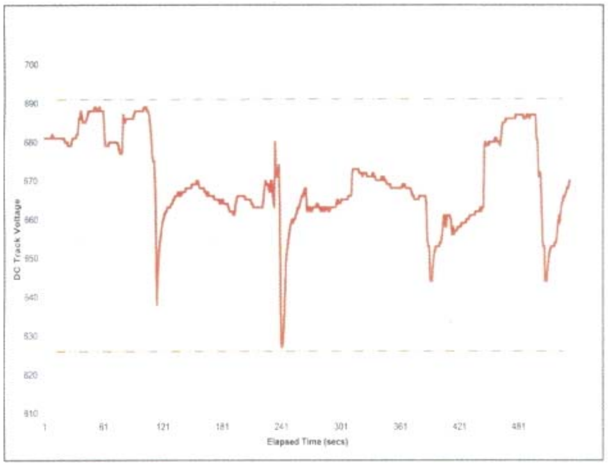


Fig 3 Revenue Line With Out KESS

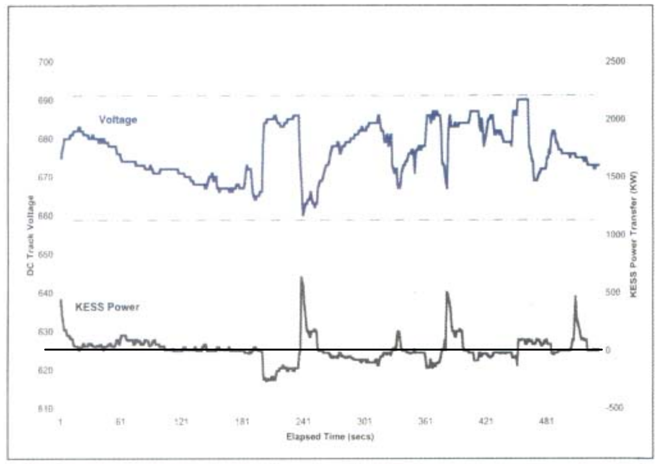


Fig 4 Revenue line with KESS operational

With the KESS system operational and a test train accelerating from a standing start the voltage never dropped below 625v even under the worst conditions with a revenue train passing the test track site at the same time. Figure 4 shows the KESS system connected to the system during normal operations at a similar time of day to the previous recording shown in figure 3. Here the voltage drops from 685v to 660volts with the **KESS** unit supplying approximately 900kW to the system during the train's acceleration.

Energy Recovery

Under test conditions with a 4-car test train the results showed that the energy recover was proportional to the load carried Figure 4 also shows the re-generative braking energy being absorbed by the KESS system at the rate of 250kW down to 150kW over a period of approximately 50seconds. During this operation the KESS system recovered 2.5kWh of energy. This was a normal 8 car train travelling on the revenue line at normal speed where as the trials were carried out with the train accelerating and braking within the length of the test track (not as fast or as heavy, energy being proportional to the speed squared and the trains mass).

Trial description	Load with out KESS	Load with KESS	Saving
Energy consumption trial with lightly loaded 4 car train	1.225 kWh	1.100 kWh	10% reduction in energy
Energy consumption fully loaded 4 car train	1.346 kWh	1.141 kWh	15% reduction in energy used

One interesting test in view of the recent problems experienced by New York & the Eastern Seaboard of the US along with Italy and London involved switching all power off to the test track to see how far the KESS unit could make the train travel on KESS energy alone. (Simulating the recent losses of power)

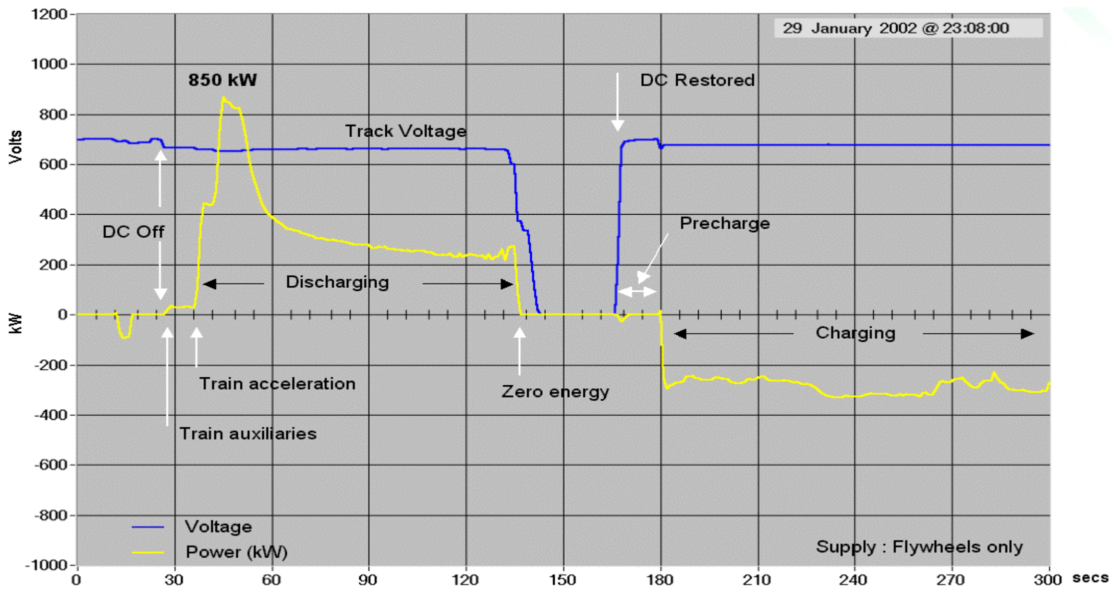


Fig 5

The results are shown in figure 5. The train reached a speed of 28mph travelling for a period of 1.7 minutes when the KESS systems energy was exhausted. At this point the train had travelled approximately 0.75 of a mile and the automatic train braking system came on due to the track voltage having collapsed. These trials have shown: -

- Traction voltage can be supported with out the need for new grid connected substations allowing more powerful trains to operate on the same system.
- Significant and measurable reductions in energy use will be achieved when this type of system is employed network wide
- Enhancement of the networks receptivity will allow the capture of the re-generative braking energy of the new ac powered trains

Lyon France.

The primary objective of this installation was to enhance the systems receptivity to the braking energy associated with the gradient saving both energy and brake maintenance, the energy saved being used to feed both lines A and C during train acceleration. Working with El a major French electrical contractor, the first phase has been installed and is working exactly as modelled. In this installation 3, 200kW machines have been installed in the substation feeding line C (rack and pinion line due to the steep gradient) and the conventional line A. In this case unlike Far Rockaway instead of the machines being set up to give both voltage support and a limited level of energy recovery, they were set up to give the maximum level of energy recovery. This system has been operation al for approximately 3 months and is working well. The second phase of the project is to fit an energy recovery system on line D (a MAGGALY automated system).

Paris Metro (RAPT)

Contracts have been signed for two systems to be fitted to the Paris Metro system. In one case the system is being used to allow the complete refurbishment of a grid connected sub station without loosing the service. It will take anything up to a year to complete the refurbishment during which time the KESS unit will be set up to act as a voltage support system taking the place of the grid connected substation. When the refurbishment is complete the control algorithm will be re-set to give maximum energy recovery along side the conventional substation. The second installation will be used at the end of a line where the voltage control is unsatisfactory. We will be reporting these results early next year.

Wind Turbine Output smoothing.

Fuji: - Mount Obu, Oki island, Japan.

In this application a single 200kW KESS unit has been fitted to a 600kW wind turbine to smooth the output from the turbine. Working in conjunction with Fuji who designed the interface between the dc output of the KESS and the ac output of the wind turbine, the overall variability of the turbine output due wind gusting, pitching and yawing of the blades is significantly reduced. The results of a typical two-minute period are shown in figure 6 and photograph of the site is shown in fig 7.

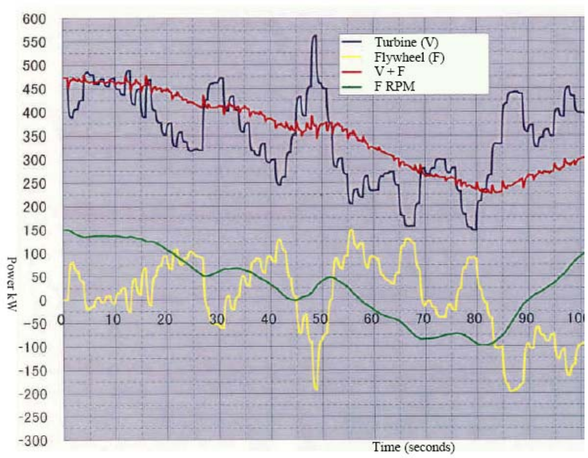


Fig 6

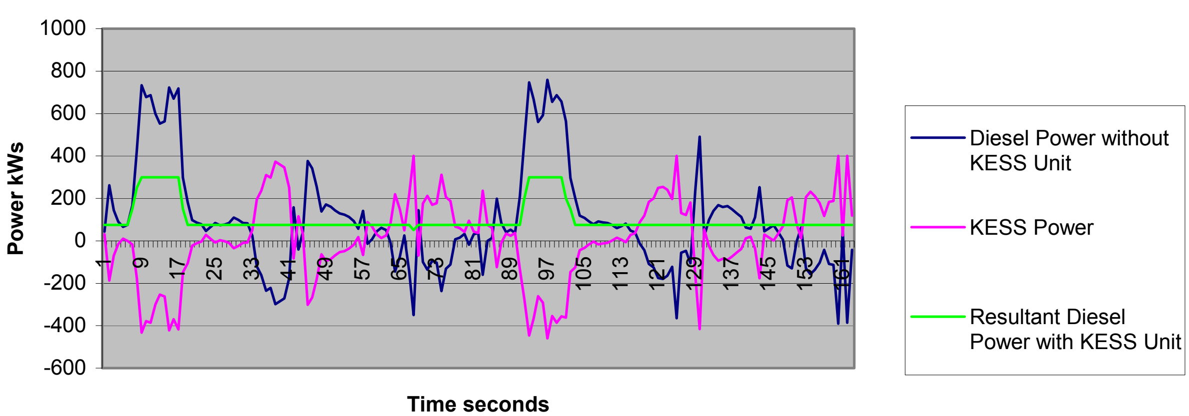
Fig 7

Wind Turbine, Mount Obu, Oki Island, Japan Courtesy of FUJI

Quayside Cranes / Mining Winches.

The objective of these applications is to smooth out the load applied to the system and take advantage of the re-generative braking energy. The first application is a crane mounted on an unloading barge. In this the KESS units are mounted on Gimballed frames to allow for the barges movement. Electrically, the dc out put from the KESS units is connected directly to the dc bus of the barge. The control algorithm is set up to control the dc voltage. As a result the power fluctuations associated with the cranes operation are smoothed as shown in figure 8 with the system both recovering regenerative energy from the cranes braking system and supplying power to peak lop the demand. The modelling results suggest that one of the two 800kW diesel generator-sets can be removed and the others output can be trimmed to only 40% of its design output This results in a savings ranging from 30% to more than 50% depending on how the crane is operated.

Fig 8 Effects of adding a KESS unit on Diesel Power for Crane Cycle 4



A second system that is based on re-locatable containerised 2MW system (fig 9) is currently being considered. Figure 10 shows the results of the modelling exercise in which the regenerative energy of the winch as it brakes is recovered and used to peak lop the acceleration phase of the winch. The potential energy saving is of the order of 20% due to the reduced peak power demand and the smoother load being applied by the system.

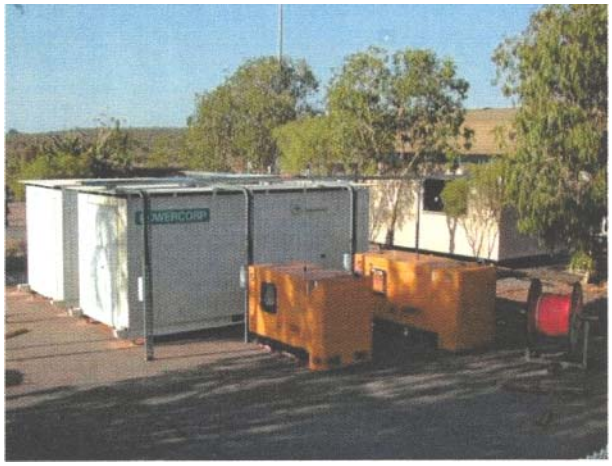


Fig 9 Re-locatable KESS System for use in remote areas with Wind Turbines, Mining Winches etc.

Effects of adding 2MW KESS Unit to a Mining Winch

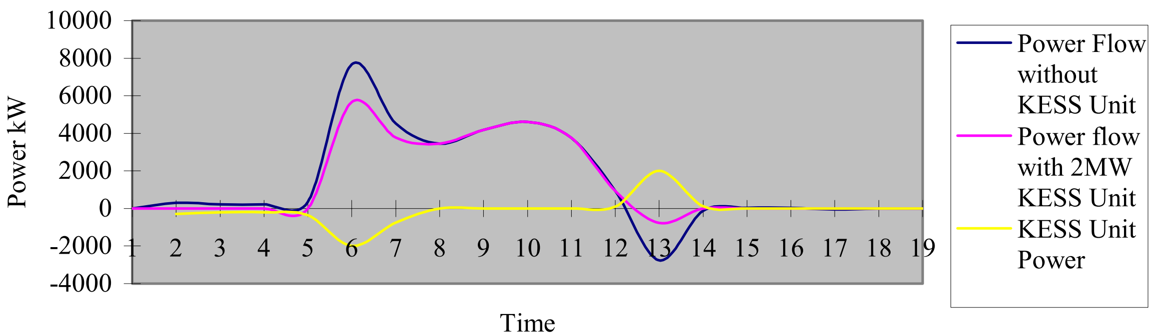


Fig 10

CONCLUSIONS

1. The use of high speed kinetic energy storage systems can bring significant benefits to traction and other cyclic/ variable load applications in terms of energy saving, reduction in peak demand and system reinforcement (asset deferral)
2. High Speed Kinetic Energy Storage systems can bring significant benefits to variable sources of energy such as Wind and Wave power where their variability can be smoothed out allowing a greater proportion of the networks energy to be sourced from these renewable technologies with out introducing instability.
3. The UPT KESS system is being successfully applied to a range of power management problems and making significant savings in terms of energy and diesel fuel.

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